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THERMAL STORAGE WALL MODEL DEVELOPMENT IN THE DOE-2 COMPUTER PROGRAM

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ABSTRACT

The DOE-2 building energy analysis computer program is being modified by the Los Alamos National Laboratory to include thermal storage wall modeling capabilities. This paper discusses model development and validation for vented and unvented thermal storage walls and water walls in DOE-2.

The unvented wall model was validated by comparison with test-cell heating loads for both a selective surface and a night-insulated wall. The two commonly used vented wall models, the Akbari and Borgers correlations and the Bernoulli equation algorithm, were compared and tested against available wall performance data. The Bernoulli algorithm was chosen for use in DOE-2 because of its ability to simulate vent restrictions.

1. INTRODUCTION

The DOE-2 building energy analysis computer program (1) is being modified by the Los Alamos National Laboratory to include passive solar simulation capabilities. DOE-2 can be used to model the dynamic energy flows occurring on an hour-by-hour basis in single or multizone buildings. It has the added capability of simulating sophisticated heating, ventilating, and air-conditioning (HVAC) systems and their thermal interaction with the building. DOE-2 is also one of the analytical tools that can be used for demonstrating compliance with the proposed Federal Building Energy Performance Standards (BEPS).

Previous papers (2,3) discussed passive solar development in DOE-2 and the direct-gain and ventilative-cooling capabilities of the DOE-2.1 version that is now in the public domain. This paper will discuss model development and validation for vented and unvented thermal storage walls and water walls in DOE-2.

2. THERMAL STORAGE WALL MODEL DESCRIPTION

A diagram of a thermal storage wall showing the modeling capabilities and energy flows simulated by DOE-2 is shown in Fig. 1.

Solar radiation input to the wall is calculated using hourly total horizontal insolation read from a weather file and converted to direct and diffuse radiation incident on the vertical glazing surface. The window algorithms in DOE-2 are used to calculate the solar energy absorbed in, and transmitted through, the glazing(s). These algorithms allow a wide range of glazing absorptances and transmittances and up to three sheets to be specified. The user can also simulate movable insulation to cover

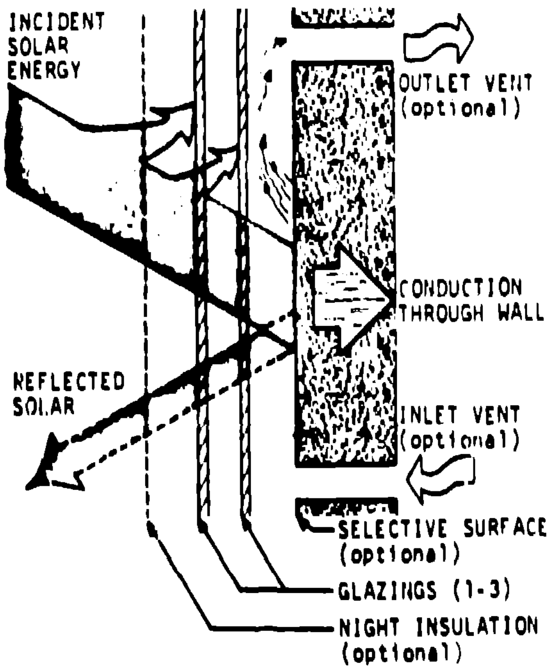

Fig. 1. Diagram of heat flows in the DOE-2 thermal storage wall model.

the wall by scheduling a decreased glazing conductance, and the wall can be assigned a specified solar absorptivity or have a selective surface.

Heat conduction through the wall into the interior space is calculated by using response factors. If vents are provided near the top and bottom of the wall, a thermosyphon effect occurs and energy will be transferred from the channel between the wall and the glass into the room by convection. A more complete description of the thermocirculation model in DOE-2 is given in Sec. 4 of this paper. This thermocirculation model simulates backdraft dampers on the vents, so reverse thermocirculation will not take place.

3. UNVENTED THERMAL STORAGE WALL

A number of approximations were made in the unvented wall model to simplify the calculative procedure. An empirical equation (4) was used to calculate a heat-transfer coefficient for convection heat transfer across the channel between the wall and the glazing. Another simplification was the use of a linearized radiation heat-transfer coefficient for the radiation heat transfer across the channel. In the DOE-2 unvented wall model, these coefficients are calculated each hour based on the past hour's wall and glazing temperatures. These approximations simplify the calculations so that the problem is reduced to solving energy balances on the outside wall and glazing surfaces. Once the outside wall surface temperature is known, conduction through the wall into the room is calculated using response factors.

This unvented-mass-wall model was validated by comparison with measured data from passive-solar test cells located at Los Alamos. These test cells are 5- by 8- by 10-ft one-room buildings that are used to test various passive solar configurations. The cells are heavily instrumented and can be operated in either a heated (constant temperature) or a free-floating temperature mode. A more detailed description of these test cells may be found in Reference (5).

Figure 2 shows the comparison of measured and predicted heating loads required to maintain a constant 82°F set point temperature for an unvented thermal-storage-wall test cell with night insulation. The predicted total heating load for the seven-day winter period examined was about 5 per cent below the measured value. Because the maximum heating set point in DOE-2 is 80°F, it is likely the results would have been even closer had DOE-2 been able to model the 82°F average air temperature in the test cell.

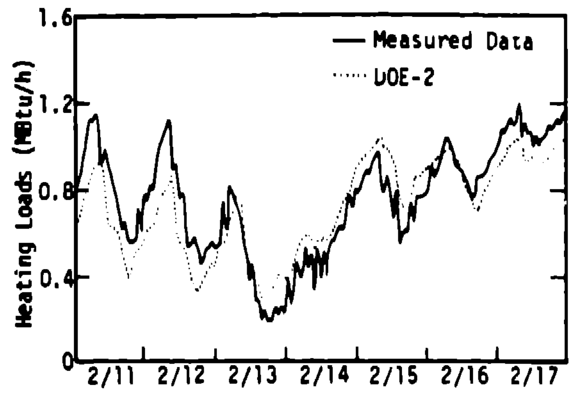

Fig. 2. Comparison of DOE-2 unvented wall model and measured data for a single-glazed test cell with night insulation.

Figure 3 shows the comparison of similar predicted and measured heating loads for an unvented wall test cell with a selective surface and no night insulation. The difference between the total predicted and measured heating loads in this case is about 9 per cent. Note that the performance of the test cell with a selective surface is superior to that of the one with night insulation.

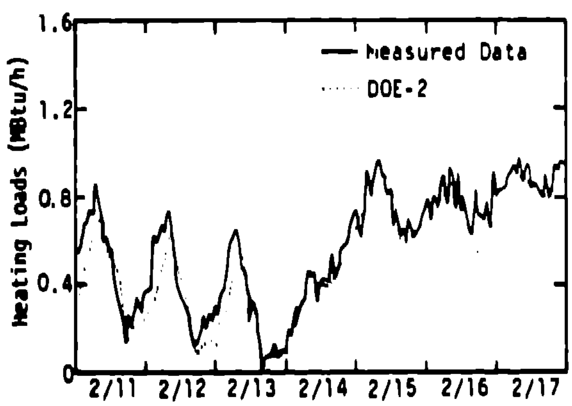

Fig. 3. Comparison of DOE-2 unvented wall model and measured data for a single-glazed test cell with a selective surface.

4. VENTED THERMAL STORAGE WALL

Modeling of a vented thermal storage wall is more difficult than that for the unvented case because of the nonlinear nature of the thermosyphoning of air that flows through the channel between the wall and the glazing.

The DOE-2 vented wall algorithm is an iterative method. It uses the output of the solution for thermocirculation flow as the input to the solution for the wall and glazing temperatures, and vice versa, until the wall and glazing temperatures converge to their equilibrium values. When the thermocirculation energy delivered to the room and the outside wall temperature are known, response factors are used to calculate conduction through the wall into the room, as in the unvented-wall case.

There are basically two different thermocirculation algorithms used by computer programs that model vented walls. Programs such as PASOLE (Los Alamos), TRNSYS (University of Wisconsin), and SUNCODE (Ecotope Group) use a thermocirculation algorithm based on a Bernoulli equation. Computer programs like BLAST (US Army Construction Engineering Research Laboratory and Lawrence Berkeley National Laboratory) and SINDA (National Bureau of Standards) use a thermocirculation algorithm based on correlations by Akbari and Borgers (6,7).

In the Akbari and Borgers correlations, a detailed hydrodynamic computer simulation was used to calculate air flow rates and air temperatures of a vertically heated channel; the results were simplified to a set of correlations based on wall and glazing temperatures, room air temperature, and geometry. This detailed computer simulation gives an accurate solution for flow within the channel. However, it does not account for restriction to air flow from vents at the top and bottom of the wall. Correlations were developed for both laminar and turbulent flow.

The Bernoulli algorithm, on the other hand, is based on Bernoulli's equation for flow through a channel. The frictional pressure drop in the channel and pressure losses through the inlet and outlet vents are balanced by the buoyancy force of the heated air. The details of this algorithm may be found elsewhere (8). The friction factor for flow in the channel is based on fully developed flow between two parallel plates with a symmetrical velocity profile. The pressure loss coefficients for the inlet and outlet vents may be obtained by combining factors for sharp-entrance and sudden-exit region pressure drops. The values can be obtained for both laminar and turbulent flows from any standard fluid mechanics textbook (9).

The principal differences between the two thermocirculation algorithms may be summed up as follows. The Akbari and Borgers correlations account for a detailed description of flow in the channel, but they ignore pressure losses in the inlet and outlet vents; the Bernoulli-equation model provides a more approximate description of flow in the channel, but the pressure drop through inlet and outlet vents can be accounted for.

Both thermocirculation algorithms were tested and compared in the DOE-2 vented wall model. Unfortunately, few data are available in the open literature on air-flow rates and temperatures in vented walls that are suitable for validation purposes. The only measurements that were found were those presented by F. Trombe at an early passive solar conference (10), and these data were taken to study wall performance, and were not intended for the validation of computer programs.

Figures 4 through 7 show the comparison of predictions by both the Bernoulli algorithm and the Akbari and Borgers correlations to the F. Trombe data. Figure 4 shows that both algorithms predict outside wall temperatures reasonably well, but the Bernoulli algorithm is closer because it predicts a lower amount of thermocirculation in the channel, with resulting lower convection and higher wall temperatures. Figures 5 and 6 show that the Akbari and Borgers correlations significantly overpredict the outlet vent flow rate and significantly underpredict the outlet vent air temperatures. The high air flow rates in this case are compensated by the lower outlet vent air temperatures so that the predicted thermocirculation energy delivered to the room (shown in Fig. 7) is closer to the measured values than the air flow predictions were. The reason for these high air flow rates appears to be the lack of a vent restriction pressure drop in the Akbari and Borgers algorithm. In fact, the Bernoulli equation algorithm also predicted similarly high flow rates when it was simulated with very large vent areas.

Our studies have shown that if the ratio of the vent area to the channel flow cross-sectional area is 1 or less (the ratio in the case of the F. Trombe data is 0.4), then the pressure drop through the vents is significant and cannot be neglected. It appears that this is the case for many vented thermal storage wall designs.

The DOE-2 vented storage wall model using the Bernoulli algorithm was also compared with measured data from a Los Alamos test cell. Unfortunately, air flow measurements were not made at the test cell, so these could not be compared with the DOE-2 predictions as in the case of the Trombe data. Figure 8 shows the comparison of measured and predicted heating loads for the vented test cell. The predicted total heating load for the seven-day period examined was within 10 per cent of the measured value.

Although a final judgment as to the accuracy of either algorithm cannot be made without more complete testing with better measured data, the Bernoulli equation algorithm has been chosen for use in DOE-2 because of the ability to model vent restrictions.

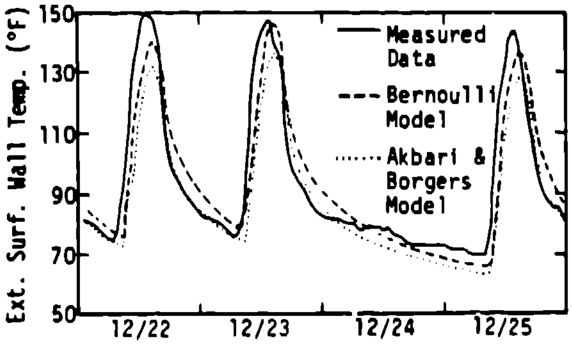

Fig. 4. Comparison of Bernoulli with Akbari and Borgers thermocirculation models and measured data for exterior wall temperatures.

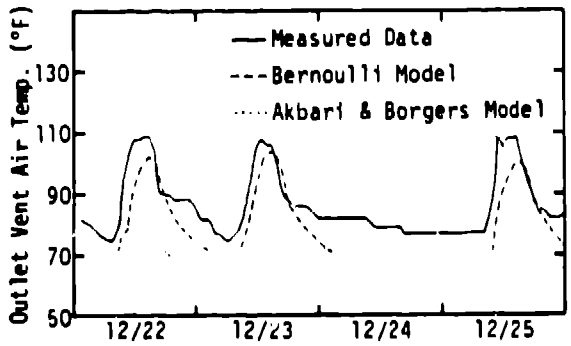

Fig. 5. Comparison of Bernoulli with Akbari and Borgers thermocirculation models and measured data for outlet vent flow rates.

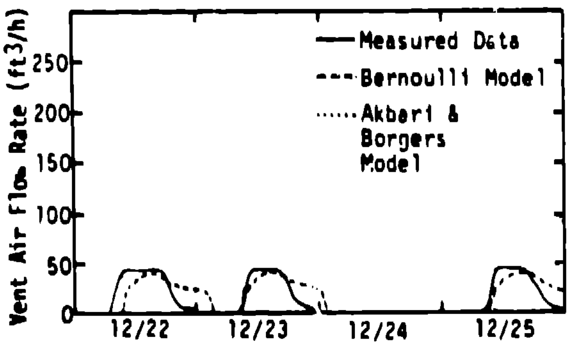

Fig. 6. Comparison of Bernoulli with Akbari and Borgers thermocirculation models and measured data for outlet vent air temperatures.

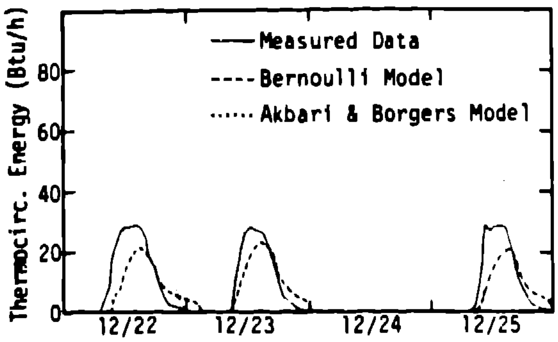

Fig. 7. Comparison of Bernoulli with Akbari and Borgers thermocirculation models and measured data for thermocirculation energy delivered to the room.

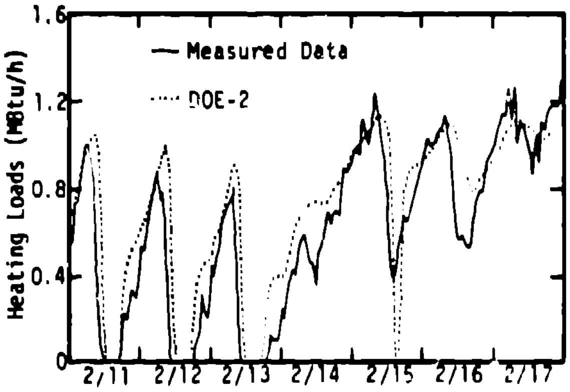

Fig. 8. Comparison of Bernoulli thermocirculation model and measured data for a vented wall test cell.

5. WATER WALL

Water is often used for heat storage in passive-solar buildings because of its high thermal capacitance. Water containers (jars, drums, and fiber glass tubes) are often placed directly behind south-facing glazing, and they behave thermally much like the wall shown in Fig. 1.

The simulation of water walls in the DOE-2 thermal storage wall model has been accomplished by treating them as unvented walls with high thermal conductivity. This can effectively account for the natural convection of the water that tends to even out the temperature distribution in the wall. Water tubes can be simulated in DOE-2 by determining the projected area of the tubes on the glazing and then calculating a wall width so that the total thermal capacitance of the DOE-2 water wall is the same as that for the actual tubes. Spaces between water tubes can be simulated by combining that glazing area into another window on the south wall. Only opaque water walls can be modeled; translucent water tubes cannot be simulated by the program now. A selective surface can be specified for the wall surface as an option.

The DOE-2 water-wall simulation was compared against measured Los Alamos test-cell data for an eight-day period in February 1980. The total heating load predicted by DOE-2 for the test cell was within 10 per cent of the measured test-cell heating load.

6. CONCLUSIONS

This study has resulted in the following conclusions.

- The DOE-2 computer program was modified to allow modeling capabilities for unvented thermal storage walls. Comparison of DOE-2 predicted heating loads with measured test-cell heating loads indicated very good agreement.

- The Akbari and Borgers correlations and the Bernoulli algorithm were examined for use in modeling the thermocirculation in the vented wall model. Although the Akbari and Borgers correlations are based on a more accurate description of flow in the channel than the Bernoulli algorithm, they do not account for vent-restriction pressure drops. The Bernoulli algorithm was chosen for use in the DOE-2 model because of its ability to model pressure drops through vents, and comparison of predictions based on this algorithm with measured data from F. Trombe and Los Alamos test cells indicated acceptable agreement.

- By proper selection of effective thermal conductivity, the unvented wall model can be used to simulate water walls. Comparison with measured test-cell testing loads indicated acceptable agreement between DOE-2 and the measured data.

7. ACKNOWLEDGMENTS

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